§ 9. Atomic and Molecular Processes in Divertor Plasmas

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The objectives of this workshop were as follows: With the aim of understanding the phenomena taking place in the divertor plasmas, and further, to control these plasmas, we summarize our present knowledge relevant to the divertor and peripheral plasmas. Here, "the knowledge" means the grasp of the plasma phenomena with the underlying collective phenomena of atoms and molecules, and further, the elementary processes consisting the collective phenomena. At the same time, we investigate possible future activities to be undertaken by the Center.

The plasmas of the present interest are of low temperature with relatively high density. In these circumstances, low-ionized stage ions or even neutral atoms and molecules are important. In divertor plasma, in particular, molecules are considered to play an essential role.

The divertor plasma in JT-60U was investigated by uv-visible spectroscopy, and the ion temperature was determined. A part of the results could be interpreted consistently, but some other results remained as mysteries. From the population distribution of excited neutral hydrogen atoms, the state of ionization dynamics of the plasma was investigated, and both the recombining-plasma component and the ionizing-plasma component were found to contribute to the populations, depending on the condition. For LHD, the spatial images of the plasma, the shape of which reflects the magnetic field configuration, were shown, and were compared with the results of the simulation for various quantities, *i.e.,* densities of atoms and molecules, electron density and temperature. Spectroscopic measurements of line intensities of berylliumlike carbon or oxygen were reported. Some of them were quantitatively interpreted, but some others show inconsistencies with the present understanding of the plasma.

A couple of years ago, a new recombination process of a plasma, M(olecular) A(ssisted) R(ecombination), was proposed, which was effective in rather high temperatures where the recombination rate coefficient of the conventional recombination is rather small. By the work of one of the present members, it turned out that the effective recombination rate coefficient is strongly dependent on the initial vibrational state of molecular hydrogen: molecules with the vibrational quantum number $v = 4 - 6$ have larger rates than those with $v = 0$ by an order. It was further shown that re-distribution over the vibrationally excited levels cannot be treated by the conventional collisional -radiative method. It was thus emphasized that the initial distribution over the vibrational levels of hydrogen molecules is essential in predicting and controlling the performance of the divertor plasma. It was also pointed out that hydrogen atoms reflected from the solid surface can be in excited states. A preliminary calculation results were reported.

In divertor plasmas, the role of hydrocarbon molecules could also be important. Our knowledge about charge exchange recombination process in which small hydrocarbon molecules are involved is progressing rapidly.

New findings were reported from two divertor simulators in Nagoya University. In laser absorption spectroscopy on the H_α line, its fine structure was resolved, and the component intensities were found to be in accordance with the population distribution according to the statistical weights. The population distribution of the $n = 2$ atoms over the chamber was determined, and under certain conditions, the distribution had a hollow profile, which is against any reasonable assumption about creation and diffusion of the excited atoms and ions. The fluctuations of the electric potential were observed together with those of the H_α line intensity, and it was concluded that the simulator plasma was rotating around its axis.

The intensity of emission line is proportional to the ionization flux and it is also proportional to the recombination flux. When the plasma is in ionization balance, where the ionization flux and the recombination flux are equal and takes the maximum at around the temperature at which the density of the ions under consideration is equal to that of the ions in the next ionization stage. This temperature is called the optimum temperature. Thus, the emission intensity takes the maximum at around this temperature. However, the majority of the laboratory plasmas are far from ionization balance. When both the densities are kept equal and constant and the temperature is changed over a wide range, the emission intensity is high in low temperatures, indicating that the recombination flux is large, and in high temperatures, the intensity is again high corresponding to the high ionization flux. At around the optimum temperature, the emission intensity takes the minimum, and the absolute value is exactly equal to the maximum for the case of ionization balance mentioned above. This feature is actually observed in many experimental observations, though its significance is not recognized.